Published by the American Meteorological Society, Boston, Mass.

THE ROLE OF REAL-TIME INTERACTIVE PROCESSING IN SUPPORT OF WATER RESOURCES FORECASTING IN THE MODERNIZED WEATHER SERVICE

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1. INTRODUCTION

Proper management of water resources is vital to the Nation's economy, the quality of our environment, and our overall social well-being. Increased resource demands, pollution, and climate variability have made water a scarce resource in most areas at one time or another and have stressed our water resources systems. While some parts of the Nation are experiencing water shortages, other parts may be experiencing serious flooding. Water management decisions that affect water resources systems are a daily routine. Industries and utilities must decide how much effluent can be safely discharged into an estuary without adversely affecting water quality and endangering fish and wildlife. Reservoirs are continually operated with the conflicting objectives of flood control, water supply, hydropower generation, navigation, water quality, recreation, etc. Figure 1 shows how these objectives work against one another by seeking to raise/lower the reservoir pool level and to hold/release water. In most cases, these water management decisions are based on localized ad-hoc information systems that cause inefficient and wasteful utilization of the Nation's water resources.

The science of real-time hydrologic forecasting, and potential computer and telecommunications resources to support the associated data processing, has reached the point that significant advances can now be made in river forecasting to provide improved information for water managers. The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) is working with a number of other federal, state, multi-state, quasi-governmental and private sector organizations toward cooperative efforts in this area. As a part of these collaborative efforts, NOAA is planning a new initiative called Water Resources Forecasting Services (WARFS).

This paper outlines the major system components of WARFS and discusses the role of real-time interactive processing in providing improved forecast products for water management. Emphasis has been placed on the NWS Interactive Forecast Program (IFP) because it represents a critical component of the WARFS technologies and because of its advanced state of development.

2. WATER RESOURCES FORECASTING SERVICES

The WARFS Initiative will provide urgent improvements in NOAA hydrologic prediction services. The infrastructure for WARFS is the current National Weather Service River Forecast System (NWSRFS). The NWSRFS is at the heart of WARFS as is shown schematically in Figure 2. WARFS model and data improvements within the NWSRFS will benefit all scales of forecasting, bringing badly needed improvements in flood warnings as well as longer-term forecast services. WARFS will take advantage of both hardware and software components of the NWS modernization programs including the Next Generation Weather Radar (NEXRAD) called WSR-88D, the Automated Surface Observing System (ASOS), and the Advanced Weather Interactive Processing System (AWIPS). The NEXRAD and ASOS programs will provide much of the necessary technology toobserve precipitation amounts on a nationwide basis at the temporal and spatial resolution required. Achieving the required accuracy of precipitation estimates, however, will require data management, integration, and analysis procedures which incorporate a large variety of precipitation data sources from other federal, state, and local gage networks. The AWIPS system provides a modern interactive processing environment which will be the center of all forecast operations in an office. Data analysis and quality control, forecast modeling, forecast interpretation, and production formulation will be carried out interactively at modern workstations, providing forecasters with a milieu for efficient and timely development of WARFS products and services. The data and computer systems provided by the NWS modernization programs, along with the technology of advanced hydrologic and climate forecast models will be used to: 1) support forecast service requirements of government and quasi-government water managers, 2) provide basic water resources forecasts to private sector intermediaries, who will tailor the forecasts to serve specific industries, 3) satisfy needs for forecast services at near-, mid-, and long-term time scales for a wide variety of water use situations nationwide, 4) provide critical information on hydrometeorological forecast reliability that can be used for risk-based water management decision-making, 5) incorporate improved weather and climate forecast information into hydrologic models, and 6) improve other short- and mid-range forecast capabilities.

2.1 National Weather Service River Forecast System

The NWSRFS is a software system (over 350,000 lines of computer code) consisting of many programs, which are used to perform all steps necessary to generate streamflow forecasts. The system includes the Calibration System (CS), the Operational Forecast System (OFS), and the Extended Streamflow Prediction (ESP) System.

a. Calibration System -- The CS performs the tasks needed to process historical hydrometeorological data and to estimate model parameters for a specific basin. The models simulate snow accumulation and ablation, calculate runoff, time distribute runoff from the basin to the basin outlet, and channel route streamflow. The NWSRFS is a modular system that allows the hydrologist to select from a variety of models and to configure them in a manner that is descriptive of the basin. All of the models are available to the Calibration, Operational Forecast, and ESP systems. As part of the calibration procedure, for a particular basin, the simulated streamflow is statistically and visually compared to the observed streamflow to determine the

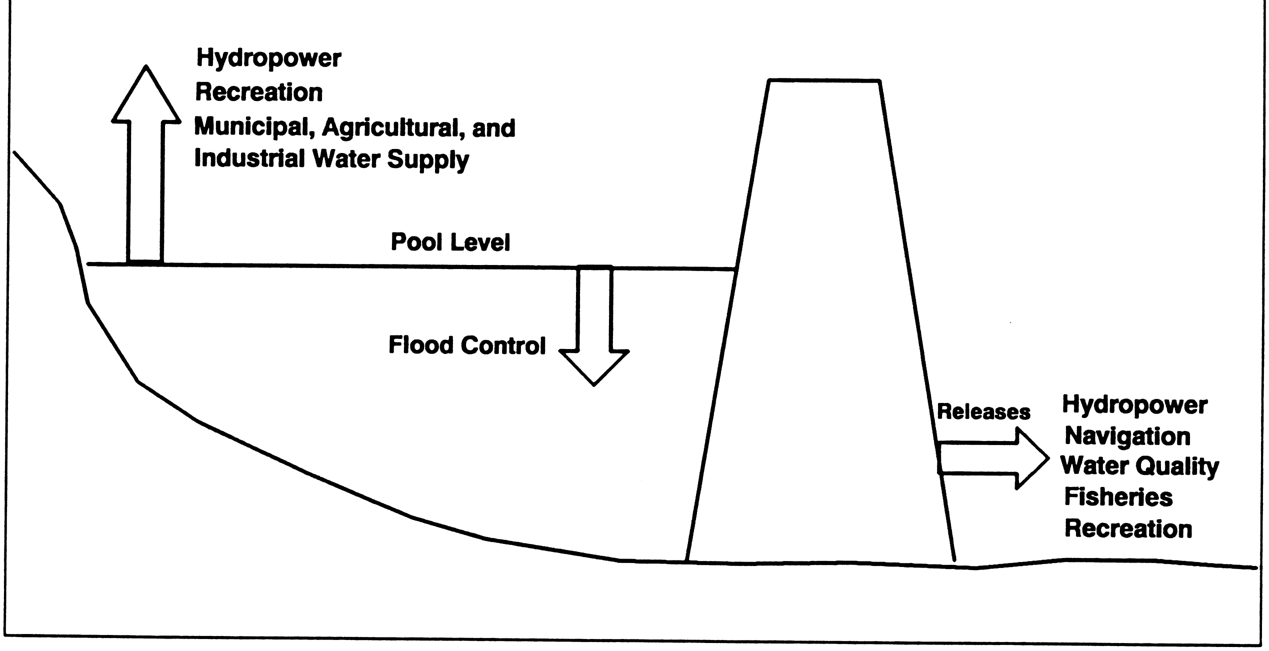

Figure 1. Reservoir Operations

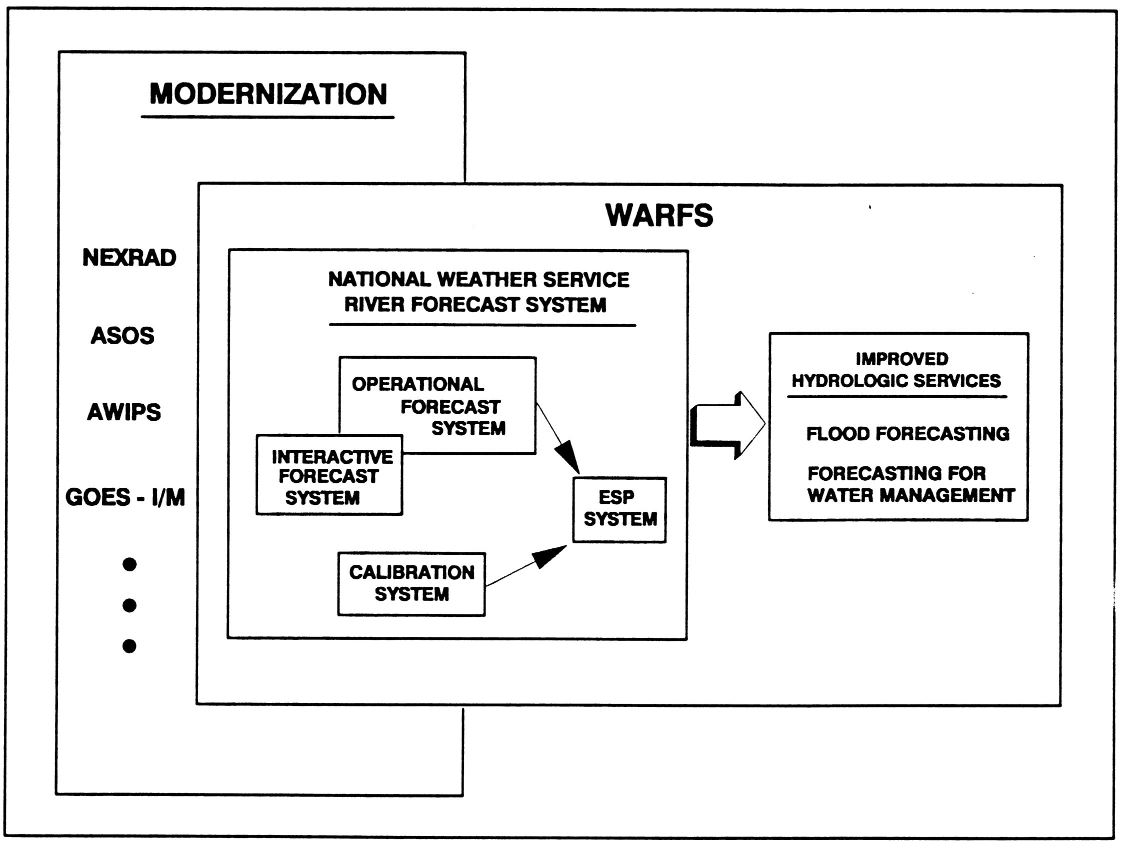

Figure 2. WARFS and the Modernized Weather Service

necessary model parameter adjustments. The ideal model parameters are those with which the model simulated streamflow most closely matches the observed streamflow. Brazil and Hudlow (1980) discuss calibration procedures in more detail.

b. Operational Forecast System -- Once the models have been calibrated for a basin, the models can be used operationally with real-time hydrometeorological data to forecast streamflow. The OFS contains three major components that are needed for operational river forecasting: Data Entry, Preprocessor, and Forecast. The Data Entry Component is a set of programs that transfer hydrometeorological data from a variety of sources to the observed data base. The Preprocessor Component reads raw station data, estimates missing data as required, and then uses these data to calculate mean areal time series of precipitation, temperature, and potential evapotranspiration for a particular basin. These processed time series are used by the Forecast Component to perform requested hydrologic and hydraulic simulations. The Forecast Component stores parametric data for the models, as well as information that describes the basin connectivity of the river system. In addition, the Forecast Component maintains an account of the current model states. These states describe the hydrologic condition of the basin, including the snow cover, soil moisture, and channel storage. They are needed as starting points for subsequent forecasts. The Forecast Component also has the ability to update these model states using observed data and to display the result of the simulation.

c. Extended Streamflow Prediction System -- ESP is the portion of the NWSRFS which enables a hydrologist to make extended probabilistic forecasts of streamflow and other hydrological variables (Day, 1985). A schematic of the ESP procedure is shown in Figure 3. ESP assumes that historical meteorological data are representative of possible future conditions and uses these as input data to hydrologic models along with the current states of these models obtained from the Forecast Component. A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. The streamflow time series can be analyzed for peak flows, minimum flows, flow volumes, etc., for any period in the future. A statistical analysis is performed using the values obtained from each year's simulation to produce a probabilistic forecast for the streamflow variable. This analysis can be repeated for different forecast periods and additional streamflow variables of interest. Short-term quantitative forecasts of precipitation and temperature can be blended with the historical time series to take advantage of any skill in short-term meteorological forecasting. In addition, knowledge of the current climatology can be used to weight the years of simulated streamflow based on the similarity between the climatological conditions of each historical year and the current year.

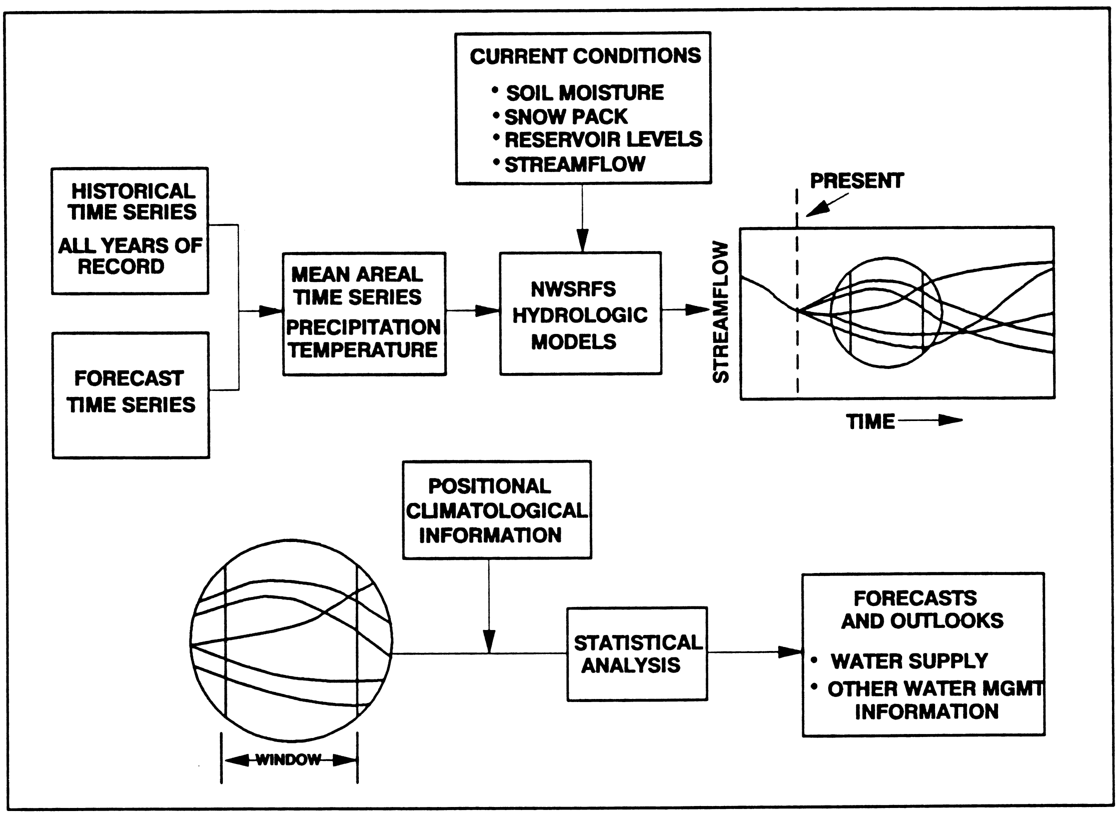

Figure 3. The ESP Procedure

ESP allows flexibility in the streamflow variables which can be analyzed, the capability to make forecasts over both short and long time periods, and the ability to incorporate forecast meteorological data into the procedure. Because of ESP's flexibility and conceptual basis, it has many applications, including water supply forecasts, flood outlooks, and drought analysis. The forecast information provided by ESP is particularly useful during droughts. The minimum streamflow, minimum reservoir level, or streamflow volume can be estimated for any exceedance probability level. By observing how many of the historical year's simulations dip below critical levels, the user can define the risk of running short of water. If the risk exceeds an acceptable value, drought contingency measures can be taken. The streamflow time series generated by ESP could be used as input to other simulation models to investigate how water supply operations might be improved. These streamflow time series represent possible occurrences based on both the current conditions and forecast data. ESP provides water managers with information needed to quantitatively assess the severity of the drought, so that measures can be taken to reduce the risk of running out of water to an acceptable level.

2 Interactive Processing

e advanced observations, enhanced data integration techniques, proved models, and expanded historical and real-time drometeorological data bases provide a strong technological se for comprehensive water resources forecast information. ese complex data and software systems can only be effective, wever, if the user interfaces are designed for efficient eraction with the hydrometeorologist. In the future, eractive processing will play an extremely important role in storical data analysis, model parameter estimation, real-time ta quality control, precipitation field estimation, hydrologic recasting, and ESP post-analysis and interpretation. Interactive ograms are currently being developed to assist the drometeorologist in estimation of the precipitation field from ge, radar, and satellite data and to assist the hydrologist in the eparation of streamflow forecasts. The Interactive Forecast ogram (IFP) is an enhancement of the NWSRFS Forecast omponent that provides the forecaster with a powerful, teractive, and user-friendly interface for real-time hydrologic recasting. The structure and capabilities of the IFP are scussed in more detail below.

. NWSRFS INTERACTIVE FORECAST PROGRAM

s part of the NWS Office of Hydrology PROTEUS Project, the P is being developed to prototype the hydrologic forecasting vironment expected to be available in NWS River Forecast enters in the AWIPS era. The major components that make up e IFP are 1) the hydrologic models in the NWS River Forecast stem, 2) the X window protocol available on scientific orkstations running UNIX, 3) the X toolkits available to ovide building blocks for applications program interface evelopment, and 4) commercial off-the-shelf software for the evelopment of graphical display and interactive program control odules. See Adams (1991) for a discussion of the philosophy of aphical user interfaces, and Page (1991) for further information n the structure of the IFP.

.1 Hydrologic Models in the IFP

ll of the NWSRFS hydrologic models that have been used by WS RFC forecasters since the introduction of the NWSRFS perational Forecast Program in 1984 are available to forecasters sing the IFP. Identical hydrologic modelling code is being run in e interactive program on the workstations as has been run in e batch NWSRFS on the NOAA Central Computer Facility.

3.2 Workstation Capabilities

The windowing capabilities of a scientific workstation allow the forecaster to have multiple processes displayed simultaneously. Because the order in which a forecaster might want to see or control various parts of the modelling system is not fixed from one forecast to the next, independent programs linked through access to common databases have been written under the X window umbrella. These programs provide the forecaster with flexibility to process and display only those parts of the IFP that are important for the current forecast event.

3.3 Graphical Interface Development

There is an extensive set of graphical input/output software that has been developed to provide applications programmers with functions that can be called to display such interface components as pushbuttons, pulldown menus, text edit boxes, etc. These components, known as widgets, are part of the X toolkits available as part of the X window software development environment. The current version of the IFP is being written using the Open Software Foundation (OSF) version of Motif widgets. By using an OSF widget set the IFP will not be locked into any particular hardware platform. This is important because the IFP is a prototype of the system that will be used in the AWIPS era under the hardware and system capabilities provided to an RFC. The IFP has been coded to avoid dependence on a particular hardware or operating system environment.

Commercial off-the-shelf graphical development software has been used to provide some of the IFP displays. This graphical package consists of two main components. One is a graphical editor with which screens can be constructed. Objects on the screen can consist of 1) simple items, such as circles, lines, text, etc., and 2) complex graphs such as bar or X-Y plots. The objects on a screen can be linked to data sources. As values of the data sources change the objects can change color, replace one picture with another, plot data on a graph, etc. The screens with their associated data sources can be stored in files as views which can be retrieved later from the applications program. The second main component of the commercial graphics package is a set of functions which allow applications programs to load previously stored views, associate data with the appropriate data sources, and manipulate the screens as desired. This two-part graphical package is very effective for program development because it cleanly divides the process of developing a graphical user interface into 1) creating the scene the user looks at, and 2) interacting with the applications code to perform the appropriate tasks.

3.4 Hydrologic Forecasting with the IFP

The purpose of the IFP is to allow the forecaster to use hydrologic expertise and judgement to develop a forecast while streamlining the tasks required to produce the forecast. The approach has been to provide a graphical user interface which presents information needed to make better hydrologic decisions, and allows any required adjustments to be made with the minimum of effort (Wiele and Smith, 1991).

Based on 1) parametric information describing the structure of the models used at each forecast point, 2) network information describing how the forecast points are linked, and 3) observed data describing the locations of meteorological and hydrological sensors as well as their current data values at the time the forecast is made; the forecaster can decide whether to accept a model generated forecast or make needed adjustments (Wiele and Smith, 1991).

This information is presented to the forecaster in a variety of graphical displays. In broad terms, the displays consist of those for user orientation and for data presentation. An example of a being modelled in the current IFP session; the display shows the connectivity of the points and the current state of the streams in each forecast area (Fig. 4). Model inputs and simulation results are presented in a graphical plot display (Fig. 5). More details about these displays can be found in Page (1991).

3.5 Run-time Modifications

The major advance in hydrologic forecasting introduced by the IFP is to allow the forecaster to interactively make changes to the parameters, data, or current conditions used for hydrologic simulation and quickly see the results of those changes. The mechanism for making changes that will affect model simulations is called a run-time modification. In general, these modifications can be categorized into those affecting time series and those affecting a specific hydrologic model. These run-time modifications are described in more detail in Page (1991) and Wiele and Smith (1991).

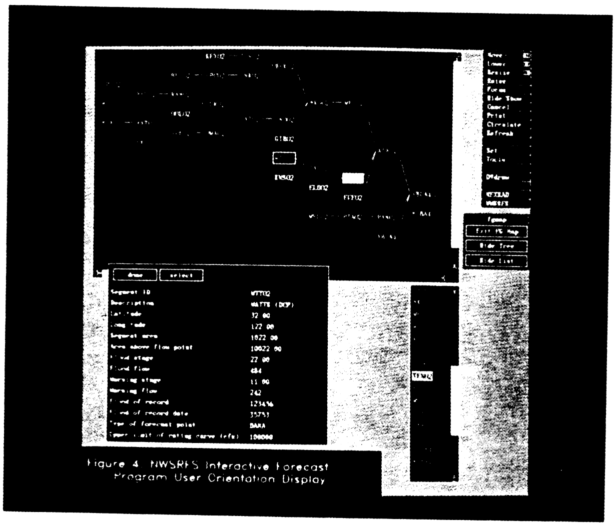

Figure 4. NWSRFS Interactive Forecast Program User Orientation Display

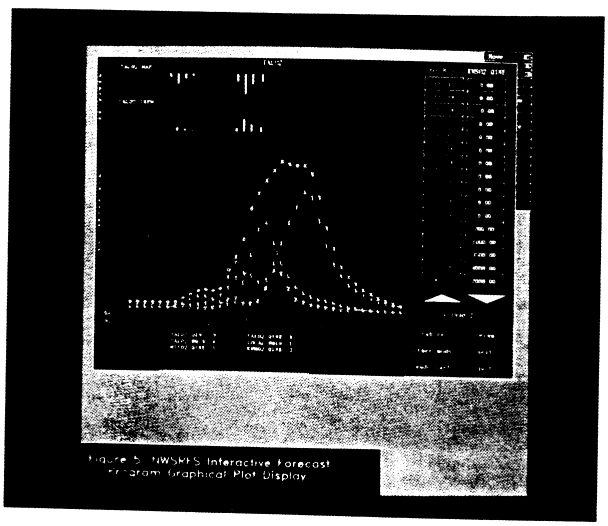

Figure 5. NWSRFS Interactive Forecast Program Graphical Plot Display

4. SUMMARY/CONCLUSIONS

The purpose of any adjustments made through the IFP is to provide a better representation of the current hydrometeorologic conditions within a forecast area so that forecasts starting from those conditions can be more accurate. The improved data collection and analysis systems of NEXRAD and ASOS work together with the IFP to provide the best possible information for probabilistic analysis by the ESP program.

In addition, advanced data and computer systems have provided an efficient environment to perform data analysis, forecasting, and interpretation. The IFP demonstrates how a complex software system can be made manageable and responsive to a hydrologist operating under severe time constraints.

As is proposed in the WARFS Initiative, all of these systems working together will ensure that the best possible hydrometeorological information is available on which to base probabilistic water resources forecasts. This all leads to the best available information being presented to decision makers so as to optimize the benefits which can be realized from our water resources.

5. ACKNOWLEDGEMENTS

This work is supported, in part, by the AWIPS program office. The authors would like to thank Ms. Donna Page for her review of the manuscript, Ms. Annette Cardona for her help producing the figures, and Mmes. Elaine Hauschildt and Virginia Radcliffe for their assistance in the final document preparation.

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